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Comparison of alternative postharvest quarantine treatments for sweet cherries

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Abstract

The effects of controlled atmosphere heat treatments (CATTS) and irradiation on sweet cherry fruit quality were compared to fumigation with methyl bromide. ‘Bing’ and ‘Rainier’ sweet cherry varieties were tested from the Yakima and Wenatchee, WA growing areas. Irradiated cherries had overall quality better than methyl bromide-treated cherries. CATTS-treated ‘Rainier’ cherries, but not ‘Bing’, had more pitting and bruising after 14 days of storage than fruit from other treatments. Both cultivars treated with methyl bromide had poorer stem quality than controls. CATTS-treated ‘Bing’ fruits had poorer stem quality after 7 and 14 days of storage than the controls. This research demonstrated that both irradiation and CATTS have potential for alternative quarantine treatments for sweet cherries. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Sweet cherry; Quarantine; Irradiation; Controlled atmosphere/temperature treatment system

1. Introduction

Sweet cherries, *Prunus avium* L., produced in the U.S. must be fumigated with methyl bromide (MeBr), to meet quarantine restrictions imposed by some importing countries (FAO, 1983; Moffitt et al., 1992). Sweet cherries are exported to Japan following a fumigation treatment to kill any potential codling moth (*Cydia pomonella* L.) larvae, an insect Japan has identified as a quarantine pest. The Pacific Northwest produces 87% of the sweet cherries in the U.S., and exports approximately 30% of its crop to Japan. Due to the identification of MeBr as an ozone depleter (Anon., 1992), the U.S. Environmental Protection Agency (EPA), in accordance with the Clean Air Act of 1990 (Federal Clean Air Act, 1990), required that the production and sale of this fumigant cease after January 1, 2001. In October of 1998, the U.S. Congress amended the Clean Air Act to agree with the Montreal Protocol on both the phase-out dates and on the exemption for MeBr uses for postharvest and phytosanitary purposes. However, since the major use of MeBr is for soil sterilization, there is no guarantee that this chemical will be available for postharvest

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uses. Therefore, two viable alternatives to MeBr fumigation, irradiation and combination controlled atmosphere with hot forced air, were developed in our laboratories.

Irradiation is not a new technology, having been used for decades to sterilize medical supplies and pharmaceuticals. Spices that are ingredients in processed foods are irradiated. Irradiation does not cause the food to become radioactive, nor has there been any evidence that irradiation causes the formation of free radicals above those levels produced in conventionally cooked foods (Urbain, 1986). The U.S. Food and Drug Administration (FDA), has limited the maximum absorbed dose of radiation to <1000 Gy for fresh fruits and vegetables. At these doses, immediate mortality of infesting insect pests is not always achieved. The USDA-APHIS has established guidelines for confirming that a commodity has received the proper dose to render the target pest potentially infesting the commodity biologically 'neutralized' (APHIS, 1996). These guidelines include extensive documentation, dosimetry, and issuance of treatment certification. In fact, USDA-APHIS has already approved irradiation as a quarantine treatment for selected fruits from the state of Hawaii destined to the U.S. mainland (APHIS, 1998). This makes the U.S. the first country to approve phytosanitary irradiation of fruits. We would like to emphasize, however, that although this approval is in the Federal Register, it is not currently used on commercially marketed Hawaiian fruit. This initial approval by the U.S., along with the availability of relatively inexpensive box dosimeters, will likely facilitate the acceptance of irradiation as a quarantine treatment world-wide.

Irradiation has been shown to be effective on the two major insect pests that pose quarantine concerns in U.S.-produced sweet cherries: codling moth (*Cydia pomonella* L.) (Burditt and Hungate, 1989; Toba and Burditt, 1992; Toba and Moffitt, 1996) and western cherry fruit fly (*Rhagoletis indifferens* L.) (Burditt and Hungate, 1988). It was found that 233 Gy was required to prevent pupation of fifth instar codling moth (Toba and Moffitt, 1996) and that 97 Gy was a sufficient dose to control western cherry fruit fly (Burditt and Hungate, 1988).

Hot forced air has been used to disinfest tropical and subtropical fruits (Armstrong, 1994; Hallman and Armstrong, 1994; Mangan et al., 1998). However, the application to temperate fruits is not as commonplace. Typically, most temperate fruits are stored at cold temperatures as quickly after harvest as possible. (High temperatures are believed to compromise fruit quality.) For pome fruits, cold storage is often accompanied by controlled atmosphere (CA) storage (low O_2 and elevated CO_2), to reduce metabolism and preserve quality (Carpenter and Potter, 1994; Hallman, 1994). Effects of controlled atmosphere storage on pests infesting stored fruit are not effective due to the low temperature of the storage regime. Low temperature reduces the insects' metabolism and thus demand for oxygen. In turn, high temperatures kill infesting insect pests more effectively, but usually at the price of fruit injury due to the duration of exposure necessary to kill the pest. When heat is applied in a controlled atmosphere, the duration of the treatment can be greatly reduced, potentially reducing loss of fruit quality (Neven and Mitcham, 1996; Shellie et al., 1997). CA reduces an insects' ability to acclimate to elevated temperatures and results in suffocation because oxygen availability is lower than the increased metabolic demand of the insect. Knowledge of this effect on insect physiology has led to the development of a Controlled Atmosphere/Temperature Treatment System (CATTS) (Neven and Mitcham, 1996). Using CATTS, we have shown that the total duration of a heat treatment can be greatly reduced in time by 25–50% with the addition of controlled atmospheres. This is a great advantage over traditional hot air and hot water dips, because the reduced treatment times help preserve fruit quality.

In the summer of 1997 we performed a comparison study of irradiation and CATTS treatments against MeBr fumigation to determine whether these treatments were viable alternatives. The results of this study are detailed in this paper.

2. Materials and methods

2.1. Fruit treatments

We assessed quality in 'Bing' and 'Rainier' cherries subjected to the following postharvest quarantine treatments: MeBr fumigation (6°C, 1.13 kg m^{-3}), CATTS 1 (45°C, 1% O_2, 15% CO_2, 45 min), CATTS 2 (47°C, 1% O_2, 15% CO_2, 25 min), and irradiation (300 Gy). Fruit were stored at 1°C for 0, 7, and 14 days following treatment. Freshly harvested, unprocessed 'Bing' and 'Rainier' sweet cherries (55 kg each) were obtained from six commercial sources on the day of harvest in 1997. Cherries were divided into four treatment groups.

2.2. Methyl bromide fumigation

Cherries were hydrocooled (2–5°C) in water containing 100 ppm chlorine for 5 min then air dried in a chamber set at 2°C under a fan (2 m s^{-1}). Cherries were placed into wire mesh boxes (25.4 cm × 25.4 cm × 25.4 cm) and equilibrated to 6°C overnight. Fumigation with 1.13 kg m^{-3} of MeBr for 2 h was conducted at 6°C. Cherries were aerated for 2 h prior to removal from the chamber. They were packed into fiberboard boxes (24 cm × 18.8 cm × 16 cm) lined with 1-mm polyliners and held at 2–4°C overnight prior to the 2-h shipment by van to the ARS Tree Fruit Research Laboratory (TFRL) in Wenatchee, WA in ice coolers. The cherries were stored at 1°C until analyzed for quality.

2.3. Irradiation treatments

All irradiations were carried out in a GammaBeam 650 facility located in Richland, WA at Pacific Northwest National Laboratory (PNNL).

Cherries were hydrocooled (2–5°C) in water containing 100 ppm chlorine for 5 min then air dried in a chamber set at 2°C under a fan (2 m s^{-1}). They were packed into lined boxes and packed into ice coolers with ice packs prior to shipment by van to the irradiation facility. The fruit were irradiated at a rate of 61.29 Gy min^{-1} to a dose of 300 Gy. Following treatment, they were held at 2–4°C overnight prior to shipment by van to the Tree Fruit Research Laboratory (TFRL) in Wenatchee, WA in ice coolers. The cherries were held at 1°C until quality analysis.

2.4. CATTS

Cherries were placed directly into a vented bottom fruit lug (38.1 × 53.35 × 15.24 cm, OnoPac, Hilo, HI) with a vented rubber liner placed on the bottom. CATTS chambers were pre-equilibrated at treatment conditions (CATTS 1: 45°C, 1% O_2, 15% CO_2, 2 m s^{-1} air speed, > 90% RH and CATTS 2: 47°C, 1% O_2, 15% CO_2, 2 m s^{-1} air speed, > 90% RH). Cherries were placed into the lug changer, attached to the CATTS chamber, flushed for 2 min with N_2, and placed into the CATTS chamber. At the end of the treatment (45 min for the 45°C treatment and 25 min for the 47°C treatment) cherries were removed from the CATTS chamber and immersed for 5 min in cold (2–5°C) water containing 100 ppm chlorine. Cherries were air dried prior to packing into fiberboard boxes (24 cm × 18.8 cm × 16 cm) lined with 1-mm polyliners. Packed boxes were stored at 1°C until transported by van to TFRC for analysis.

2.5. Quality evaluation

Quality evaluation consisted of objective and subjective color, firmness, soluble solids content (SSC), titratable acidity (TA), and evaluation for defects such as pitting, bruising, and stem browning. Objective color of fruit and stems was determined with The Color Machine (Pacific Science, Silver Spring, MD) using the Hunter L, a, b system and hue colors were calculated (Hunter and Harold, 1987). Subjective color was determined using two laboratory personnel familiar with cherry color grades. Fruit and stems were rated individually for overall appearance on a scale of 1 to 3 (1 = best; 3 = worst) and the mean value reported. Firmness was determined using the Universal TA-XT2 texture analyzer equipped with a 3-mm probe set at 10 mm s^{-1} and a penetration distance after contact of 7 mm and the values were expressed in Newtons (N). SSC of the cherries was determined with an Abbe-type refractometer with a sucrose scale calibrated at 20°C. Acids were titrated to pH 8.2 with 0.1 N NaOH and expressed as percentage of malic acid. Defects (pitting and bruising) present on each cherry were graded by two laboratory personnel as present or absent.

2.6. Statistics

SAS ANOVA and ProcGLM (SAS Institute, 1985) were used to separate the means of each treatment and storage period using General Least Squares and Duncan's Multiple Range Test. Also, SAS contrasts were used to determine differences between MeBr- and CATTS-treated fruit.

3. Results and discussion

3.1. 'Bing' quality

Fruit and stem color was influenced by quarantine treatments at all storage intervals (Table 1). At 0 day external fruit L^* (ExL) values were similar between all treatments except for fruit from CATTS 2, which had lower L^* values. The lower L^* indicated a darker fruit for the CATTS 2 treatment. There were no significant differences in external fruit hue (ExHue) values (Table 1) at day 0. After 7 days of storage, external fruit L^* values for CATTS 1 and irradiated fruit were higher than the control fruit. The external fruit L^* values for the other treatments were similar. External fruit hue values between treatments at 7 days were distinctly different with fruit from CATTS 1 and 2 and irradiation displaying reduced values when compared to hue values for control and MeBr-treated fruit. After 14 days of storage, external fruit L^* and hue values were similar between the CATTS 2 and irradiation treatments.

'Bing' visual fruit scores (Table 1) were higher for CATTS 1 and 2, indicating lower visual quality, for 0 and 14 days of storage. Only CATTS 1 treatment was higher than the other treatments at 21 days of storage. Irradiation and MeBr treat-

Table 1
External fruit and stem color and visual assessment of 'Bing' cherries*

Treatment	Store	ExL	ExHue	StL	StHue	VisF	VisS
Control	0	$36.9 \pm 1.7_{AB}$	$7.76 \pm 1.5_{A}$	$50.4 \pm 3.0_{A}$	$121.9 \pm 9.4_{A}$	$1.3 \pm 0.1_{B}$	$1.1 \pm 0.1_{C}$
CATTS 1	0	$35.3 \pm 1.5_{AB}$ [a]	$9.4 \pm 1.3_{A}$	$39.9 \pm 2.7_{C}$ [a]	$129.5 \pm 8.4_{A}$ [a,b]	$1.9 \pm 0.1_{A}$ [b]	$1.7 \pm 0.1_{A}$ [b]
CATTS 2	0	$33.20 \pm 1.7_{B}$ [a,b]	$8.5 \pm 1.5_{A}$	$41.3 \pm 3.0_{BC}$	$113.4 \pm 9.2_{A}$	$1.6 \pm 0.1_{AB}$	$1.3 \pm 0.1_{BC}$
IR	0	$38.4 \pm 1.7_{AB}$	$10.0 \pm 1.5_{A}$	$43.1 \pm 3.0_{ABC}$	$119.4 \pm 9.2_{A}$	$1.4 \pm 0.1_{B}$	$1.2 \pm 0.1_{C}$
MB	0	$40.6 \pm 1.7_{A}$	$10.5 \pm 1.5_{A}$	$49.1 \pm 3.0_{AB}$	$120.7 \pm 9.2_{A}$	$1.4 \pm 0.1_{B}$	$1.5 \pm 0.1_{AB}$
Control	7	$25.9 \pm 0.7_{B}$	$12.7 \pm 0.8_{AB}$	$35.5 \pm 3.1_{A}$	$100.4 \pm 2.1_{A}$	$1.9 \pm 0.1_{B}$	$1.4 \pm 0.1_{C}$
CATTS 1	7	$29.4 \pm 0.8_{A}$ [a]	$10.1 \pm 0.8_{C}$	$41.6 \pm 3.2_{A}$ [a]	$94.7 \pm 2.2_{A}$	$2.3 \pm 0.1_{A}$ [a,b]	$2.1 \pm 0.1_{A}$ [b]
CATTS 2	7	$27.8 \pm 0.8_{AB}$	$11.8 \pm 0.8_{ABC}$	$34.8 \pm 3.2_{A}$	$94.1 \pm 2.2_{A}$	$2.3 \pm 0.1_{A}$ [a,b]	$1.9 \pm 0.1_{A}$ [b]
IR	7	$28.7 \pm 0.8_{A}$	$10.4 \pm 0.8_{BC}$	$36.2 \pm 3.2_{A}$	$95.8 \pm 2.2_{A}$	$1.7 \pm 0.1_{B}$	$1.4 \pm 0.1_{BC}$
MB	7	$27.9 \pm 0.8_{AB}$	$13.3 \pm 0.8_{A}$	$29.9 \pm 3.2_{A}$	$97.9 \pm 2.2_{A}$	$1.8 \pm 0.1_{B}$	$1.8 \pm 0.1_{AB}$
Control	14	$28.8 \pm 0.8_{C}$	$12.8 \pm 1.0_{AB}$	$28.9 \pm 0.9_{A}$	$90.5 \pm 1.8_{B}$	$1.7 \pm 0.1_{AB}$	$1.7 \pm 0.1_{B}$
CATTS 1	14	$27.4 \pm 0.9_{C}$ [a,b]	$14.6 \pm 1.1_{A}$ [b]	$31.6 \pm 1.1_{A}$	$95.1 \pm 1.9_{AB}$	$1.9 \pm 0.1_{A}$	$1.5 \pm 0.1_{B}$
CATTS 2	14	$29.6 \pm 0.8_{BC}$ [a]	$10.4 \pm 1.0_{B}$	$27.5 \pm 0.9_{A}$	$84.2 \pm 1.8_{C}$	$2.0 \pm 0.1_{A}$	$2.3 \pm 0.1_{A}$
IR	14	$31.6 \pm 0.7_{AB}$	$10.4 \pm 0.8_{B}$	$30.1 \pm 0.8_{A}$	$91.1 \pm 1.5_{B}$	$1.4 \pm 0.1_{B}$	$1.4 \pm 0.1_{B}$
MB	14	$32.6 \pm 0.80_{A}$	$12.1 \pm 1.0_{AB}$	$30.8 \pm 0.9_{A}$	$96.8 \pm 1.8_{A}$	$1.5 \pm 0.1_{B}$	$1.7 \pm 0.1_{B}$

* External fruit L^* (ExL), external fruit hue (ExHue), stem L (StL), stem hue (StHue), subjective visual fruit score (VisF), and visual stem score (VisS) are given for treatments of control, CATTS 1, CATTS 2, irradiation (IR), and methyl bromide fumigation (MB) over cold storage periods (Store) of 0, 7, and 14 days. Means followed by the same capital subscript are not significantly different from one another (Duncan's Multiple Range Test).

[a] Significantly different from MB ($P < 0.05$).

[b] Significantly differently from IR ($P < 0.05$).

Table 2
Quality assessment parameters of 'Bing' cherries*

Treatment	Store	Pitting	Bruise	Firm (N)	SS (%)	TA (%)
Control	0	$8.9 \pm 1.2_{A}$	$5.9 \pm 2.3_{BC}$	$5.4 \pm 0.1_{A}$	$18.4 \pm 0.3_{A}$	$0.72 \pm 0.02_{C}$
CATTS 1	0	$6.4 \pm 1.0_{A}$ [a]	$13.3 \pm 2.0_{AB}$	$4.2 \pm 0.1_{C}$ [a,b]	$17.8 \pm 0.2_{A}$ [a]	$0.77 \pm 0.02_{BC}$ [a,b]
CATTS 2	0	$9.7 \pm 1.2_{A}$	$14.2 \pm 2.3_{AB}$	$4.7 \pm 0.1_{B}$	$18.1 \pm 0.3_{A}$ [b]	$0.81 \pm 0.02_{AB}$
IR	0	$7.1 \pm 1.2_{A}$	$9.2 \pm 2.3_{BC}$	$4.9 \pm 0.1_{B}$	$18.2 \pm 0.3_{A}$	$0.85 \pm 0.02_{A}$
MB	0	$9.6 \pm 1.2_{A}$	$17.7 \pm 2.3_{A}$	$5.1 \pm 0.1_{AB}$	$16.9 \pm 0.3_{B}$	$0.86 \pm 0.02_{A}$
Control	7	$7.0 \pm 1.3_{C}$	$27.0 \pm 1.6_{A}$	$5.3 \pm 0.1_{A}$	$18.1 \pm 0.2_{A}$	$0.83 \pm 0.01_{A}$
CATTS 1	7	$17.2 \pm 1.3_{A}$ [a,b]	$30.4 \pm 1.7_{A}$ [a,b]	$4.1 \pm 0.1_{C}$ [a,b]	$17.8 \pm 0.2_{A}$	$0.74 \pm 0.01_{C}$ [a,b]
CATTS 2	7	$18.2 \pm 1.3_{A}$ [a,b]	$30.4 \pm 1.7_{A}$ [a,b]	$4.8 \pm 0.1_{B}$	$17.7 \pm 0.2_{A}$	$0.77 \pm 0.01_{BC}$ [a]
IR	7	$11.7 \pm 1.3_{B}$	$26.0 \pm 1.7_{A}$	$4.9 \pm 0.1_{B}$	$18.1 \pm 0.2_{A}$	$0.80 \pm 0.01_{AB}$
MB	7	$9.1 \pm 1.3_{BC}$	$18.5 \pm 1.7_{A}$	$4.8 \pm 0.1_{B}$	$17.6 \pm 0.2_{A}$	$0.83 \pm 0.01_{A}$
Control	14	$11.6 \pm 2.5_{B}$	$25.9 \pm 1.9_{A}$	$5.6 \pm 0.2_{A}$	$17.8 \pm 0.2_{A}$	$0.79 \pm 0.02_{A}$
CATTS1	14	$19.9 \pm 2.7_{A}$	$30.0 \pm 2.1_{A}$	$4.6 \pm 0.2_{C}$ [b]	$18.1 \pm 0.2_{A}$ [a]	$0.73 \pm 0.02_{B}$ [a]
CATTS2	14	$20.7 \pm 2.5_{A}$	$28.3 \pm 1.9_{A}$	$4.6 \pm 0.2_{C}$ [b]	$17.8 \pm 0.2_{A}$ [a]	$0.78 \pm 0.01_{A}$
IR	14	$15.9 \pm 2.1_{AB}$	$28.1 \pm 1.6_{A}$	$5.3 \pm 0.2_{AB}$	$17.8 \pm 0.2_{A}$	$0.78 \pm 0.01_{AB}$
MB	14	$19.8 \pm 2.5_{A}$	$27.6 \pm 1.9_{A}$	$5.0 \pm 0.2_{BC}$	$16.7 \pm 0.2_{B}$	$0.83 \pm 0.02_{A}$

* Number of fruit pitted (Pitting), number of fruits bruised (Bruise), percent soluble solids (SS), and percent titratable acidity (TA) are given for treatments of control, CATTS 1, CATTS 2, irradiation (IR), and methyl bromide fumigation (MB) over cold storage periods (Store) of 0, 7, and 14 days. Means followed by the same capital subscript are not significantly different from one another (Duncan's Multiple Range Test).

[a] Significantly different from MB ($P<0.05$).

[b] Significantly differently from IR ($P<0.05$).

ments had visual scores similar to control fruit for all storage periods.

'Bing' stem $L*$ (StL) values (Table 1) were distinctly different between quarantine treatments at the 0 days storage period, but no difference was evident at 7 and 14 days of storage for either $L*$ or hue (StHue) values. At the initial evaluation period, stem $L*$ values were reduced for the stems from the different treatments compared to the control stems. Visual assessment of the stems (VisS) (Table 1) from the CATTS 1 and 2 treatments were given higher visual assessment scores when compared to control, irradiated, treated stems indicating lower stem quality for all three storage periods. However, visual stem values were not significantly different from MeBr-treated fruit for all three storage periods.

Enhanced pitting of 'Bing' cherries was very evident for CATTS, irradiated, and MeBr-treated fruit after 7 days of storage (Table 2). However, there were no significant differences between treated fruit in the number of fruit pitted at the 0- and 14-day storage periods. Bruising was a problem for all treated fruit at the 0-day storage period (Table 2), but not for the remaining storage periods.

'Bing' fruit firmness was reduced with all quarantine treatments (Table 2). At 0 days storage, fruit firmness was reduced with all treatments except for MeBr, which was intermediate between the controls and the other treatments. After 7 days of storage, CATTS 1 firmness was less than all other treatments and after 14 days of storage the firmness of both CATTS 1 and 2 was much less than control and irradiated fruit. MeBr-treated fruit firmness was between the controls and the CATTS-treated fruit.

There was no difference in the percent of soluble solids (SSC) (Table 2) among the treatments and the controls for all the storage periods except for the MeBr treatment at 0 and 14 days of cold storage, where the % SSC was significantly lower (Table 2). Titratable acidity (TA) (Table 2), however, did show some differences. For all storage periods, CATTS 1 had a lower TA than all other treatments and controls, except for 0-day controls. There were no differences in TA between irradiated and CATTS 2-treated cherries. Interestingly though, TA was higher in all treatments compared to controls directly after treatment (0 Day).

3.2. 'Rainier' quality

'Rainier' fruit and stem color (L^* and hue values) were not significantly influenced by any of the quarantine treatments used in this study, regardless of storage (Table 3), except for MeBr-treated fruit external L^* values at 0 days storage. Visual fruit scores (VisF) (Table 3) were the highest for MeBr-treated fruit at 0 days storage, while CATTS 1 and 2 were higher at 7 and 14 days storage. Irradiation treatments were not significantly different from controls on visual fruit scores.

Stem L^* and stem hue values (Table 3) were significantly different for MeBr-treated fruit at 0 and 7 days storage. The stem L^* and stem hue values of irradiation and CATTS treatments compared favorably with those of control fruits. Visual assessment score of 'Rainier' stems (VisS) (Table 3) was increased by all quarantine treatments at the 14-day evaluation, except the irradiation treatment which was not significantly different from the control fruit. MeBr-treated fruit had the highest visual stem scores (lowest quality) for all storage periods. The increased visual assessment score for the stems from the CATTS treatments was present at only the 14-day storage period.

Fruit pitting and bruising (Table 4) increased for the CATTS treatments compared to the control fruit or fruit from the other two treatments. This increase in pitting and bruising for the CATTS-treated fruit was evident for all storage periods, except for pitting at 0 days storage. Due to the color of the 'Rainier' cherries, it is much easier to discern pitting and bruising problems. Bruising in both cultivars may have been due to increased handling of the fruit that were exposed to the CATTS treatments. Pitting may have been

Table 3
External fruit and stem color and visual assessment of 'Rainier' cherries*

Treatment	Store	ExL	ExHue	StL	StHue	VisF	VisS
Control	0	$45.7 \pm 1.4_{A}$	$26.9 \pm 1.0_{A}$	$29.2 \pm 0.6_{AB}$	$106.5 \pm 1.1_{A}$	$1.0 \pm 0.0_{D}$	$1.1 \pm 0.0_{B}$
CATTS 1	0	$46.0 \pm 1.4_{A}$	$25.8 \pm 1.0_{A}$	$30.9 \pm 0.6_{A}$ [a]	$107.3 \pm 1.1_{A}$ [a]	$1.3 \pm 0.0_{B}$ [a]	$1.1 \pm 0.0_{B}$ [a]
CATTS 2	0	$47.2 \pm 1.4_{A}$	$26.8 \pm 1.0_{A}$	$30.1 \pm 0.6_{AB}$	$105.1 \pm 1.1_{A}$ [a]	$1.1 \pm 0.0_{C}$ [a,b]	$1.1 \pm 0.0_{B}$ [a]
IR	0	$47.2 \pm 1.4_{A}$	$24.3 \pm 1.0_{A}$	$30.4 \pm 0.6_{A}$	$107.2 \pm 1.1_{A}$	$1.0 \pm 0.0_{D}$	$1.1 \pm 0.0_{B}$
MB	0	$31.7 \pm 1.5_{B}$	$25.1 \pm 1.0_{A}$	$28.4 \pm 0.6_{B}$	$101.1 \pm 1.2_{B}$	$1.5 \pm 0.0_{A}$	$1.6 \pm 0.0_{A}$
Control	7	$39.4 \pm 1.1_{A}$	$25.7 \pm 2.1_{A}$	$30.6 \pm 0.5_{A}$	$107.3 \pm 1.0_{A}$	$1.5 \pm 0.0_{C}$	$1.5 \pm 0.0_{B}$
CATTS 1	7	$39.6 \pm 1.1_{A}$	$26.5 \pm 2.1_{A}$	$30.1 \pm 0.5_{A}$	$106.2 \pm 1.0_{A}$ [a]	$1.8 \pm 0.0_{A}$ [a,b]	$1.5 \pm 0.0_{AB}$
CATTS 2	7	$39.6 \pm 1.1_{A}$	$33.1 \pm 2.1_{A}$	$30.3 \pm 0.5_{A}$ [a]	$106.6 \pm 1.0_{A}$ [a]	$1.7 \pm 0.0_{B}$ [a,b]	$1.6 \pm 0.0_{AB}$
IR	7	$40.2 \pm 1.1_{A}$	$24.7 \pm 2.1_{A}$	$30.7 \pm 0.5_{A}$	$105.7 \pm 1.0_{A}$	$1.5 \pm 0.0_{BC}$	$1.5 \pm 0.0_{B}$
MB	7	$40.7 \pm 1.1_{A}$	$26.2 \pm 2.1_{A}$	$28.7 \pm 0.5_{A}$	$97.6 \pm 1.0_{B}$	$1.5 \pm 0.0_{BC}$	$1.6 \pm 0.0_{A}$
Control	14	$42.2 \pm 1.1_{A}$	$26.6 \pm 0.8_{A}$	$26.6 \pm 0.6_{B}$	$101.9 \pm 1.6_{A}$	$1.2 \pm 0.1_{D}$	$1.3 \pm 0.0_{B}$
CATTS 1	14	$41.8 \pm 1.1_{A}$	$27.1 \pm 0.8_{A}$	$27.6 \pm 0.6_{AB}$ [a,b]	$101.8 \pm 1.6_{A}$ [a]	$2.2 \pm 0.1_{A}$ [a,b]	$1.6 \pm 0.0_{A}$ [b]
CATTS 2	14	$43.1 \pm 1.1_{A}$	$26.9 \pm 0.8_{A}$	$26.6 \pm 0.6_{B}$ [a]	$100.8 \pm 1.6_{A}$ [a]	$1.9 \pm 0.1_{B}$ [a,b]	$1.6 \pm 0.0_{A}$ [b]
IR	14	$43.0 \pm 1.1_{A}$	$25.0 \pm 0.8_{A}$	$28.4 \pm 0.6_{A}$	$101.6 \pm 1.6_{A}$	$1.3 \pm 0.1_{D}$	$1.4 \pm 0.0_{B}$
MB	14	$43.1 \pm 1.1_{A}$	$26.1 \pm 0.8_{A}$	$23.4 \pm 0.6_{C}$	$92.2 \pm 1.6_{B}$	$1.5 \pm 0.1_{C}$	$1.7 \pm 0.0_{A}$

* External fruit L^* (ExL), external fruit hue (ExHue), stem L (StL), stem hue (StHue), subjective visual fruit score (VisF), and visual stem score (VisS) are given for treatments of control, CATTS 1, CATTS 2, irradiation (IR), and methyl bromide fumigation (MB) over cold storage periods (Store) of 0, 7, and 14 days. Means followed by the same capital subscript are not significantly different from one another (Duncan's Multiple Range Test).

[a] Significantly different from MB ($P<0.05$).

[b] Significantly differently from IR ($P<0.05$).

Table 4
Quality assessment parameters of 'Rainier' cherries*

Treatment	Store	Pitting	Bruise	Firm (N)	SS (%)	TA (%)
Control	0	$3.6 \pm 0.6_A$	$2.0 \pm 0.7_B$	$5.0 \pm 0.1_{AB}$	$18.5 \pm 0.1_A$	$0.68 \pm 0.01_A$
CATTS 1	0	$4.2 \pm 0.6_A$	$6.5 \pm 0.7_A$ [a,b]	$4.6 \pm 0.1_{BC}$ [a]	$18.7 \pm 0.1_A$	$0.65 \pm 0.01_A$
CATTS 2	0	$3.6 \pm 0.6_A$	$6.1 \pm 0.7_A$ [a,b]	$4.2 \pm 0.1_C$ [a]	$18.6 \pm 0.1_A$	$0.67 \pm 0.01_A$
IR	0	$3.0 \pm 0.6_A$	$2.6 \pm 0.7_B$	$4.6 \pm 0.1_{BC}$	$18.9 \pm 0.1_A$	$0.68 \pm 0.01_A$
MB	0	$3.8 \pm 0.6_A$	$2.1 \pm 0.7_B$	$5.2 \pm 0.2_A$	$18.8 \pm 0.1_A$	$0.66 \pm 0.01_A$
Control	7	$5.2 \pm 1.1_{BC}$	$1.7 \pm 1.4_B$	$5.0 \pm 0.1_A$	$18.5 \pm 0.1_A$	$0.63 \pm 0.01_{BC}$
CATTS 1	7	$9.5 \pm 1.0_A$ [a,b]	$15.3 \pm 1.4_A$ [a,b]	$4.6 \pm 0.1_A$	$18.6 \pm 0.1_A$	$0.60 \pm 0.01_C$ [a]
CATTS 2	7	$8.3 \pm 1.1_{AB}$ [a,b]	$14.7 \pm 1.4_A$ [a,b]	$4.7 \pm 0.1_A$	$18.5 \pm 0.1_A$	$0.62 \pm 0.01_{BC}$ [a,b]
IR	7	$3.4 \pm 1.1_C$	$3.0 \pm 1.4_B$	$4.9 \pm 0.1_A$	$18.8 \pm 0.1_A$	$0.65 \pm 0.01_B$
MB	7	$3.7 \pm 1.1_C$	$2.1 \pm 1.4_B$	$4.8 \pm 0.1_A$	$18.6 \pm 0.1_A$	$0.72 \pm 0.01_A$
Control	14	$3.0 \pm 1.0_B$	$2.7 \pm 1.3_B$	$5.1 \pm 0.1_A$	$18.5 \pm 0.2_A$	$0.59 \pm 0.02_{AB}$
CATTS 1	14	$19.7 \pm 1.0_A$ [a,b]	$25.1 \pm 1.3_A$ [a,b]	$4.8 \pm 0.1_A$	$18.4 \pm 0.2_A$	$0.56 \pm 0.02_{AB}$ [a]
CATTS 2	14	$19.1 \pm 1.0_A$ [a,b]	$25.2 \pm 1.3_A$ [a,b]	$4.9 \pm 0.1_A$	$18.3 \pm 0.2_A$	$0.58 \pm 0.02_B$ [a,b]
IR	14	$3.8 \pm 1.0_B$	$3.2 \pm 1.3_B$	$5.0 \pm 0.1_A$	$18.6 \pm 0.2_A$	$0.63 \pm 0.02_A$
MB	14	$3.1 \pm 1.0_B$	$2.3 \pm 1.3_B$	$5.1 \pm 0.1_A$	$18.8 \pm 0.2_A$	$0.63 \pm 0.02_A$

* Number of fruit pitted (Pitting), number of fruits bruised (Bruise) fruit firmness in Newtons (Firm), percent soluble solids (SS), and percent titratable acidity (TA) are given for treatments of control, CATTS 1, CATTS 2, irradiation (IR), and methyl bromide fumigation (MB) over cold storage periods (Store) of 0, 7, and 14 days. Means followed by the same capital subscript are not significantly different from one another (Duncan's Multiple Range Test).

[a] Significantly different from MB ($P < 0.05$).

[b] Significantly differently from IR ($P < 0.05$).

the result of the formation of carbonic acid during CATTS treatment or prolonged exposure of hot cherries to water containing 100 ppm chlorine during hydrocooling.

Some difference in 'Rainier' fruit firmness (Table 4) was present immediately after treatment, but after 7 and 14 days of storage, no differences in firmness were evident between treated and control fruit. There were no differences in soluble solids in the treatments from those of the control fruit for all storage periods. Titratable acidity in the treatments varied only after 7 and 14 days of storage. For both 7 and 14 days of storage, MeBr-treated cherries had a higher TA than all other treatments and controls. There were no differences between CATTS 1 and 2, irradiated, and controls for storage periods of 7 and 14 days.

These results indicate that both irradiation and CATTS treatments are viable alternative quarantine treatments against both codling moth and western cherry fruit fly in sweet cherries. Comparisons of fruit quality against traditional MeBr fumigation shows that irradiation provides better overall quality than MeBr fumigation. This is in agreement with previous research (Drake et al., 1994; Drake and Neven, 1997). CATTS treatments slightly reduced fruit quality, particularly increasing fruit pitting and bruising. The commercial significance of this reduced quality has not been assessed. Further research is needed to address both extension of shelf life to achieve the standard 21 days and pitting and bruising problems with the CATTS treatments.

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References

Anon., 1992. Methyl Bromide: Atmospheric Science, Technology and Economics. United Nations Environmental Programme. Ozone Secretariat, UN Headquarters, Nairobi, Kenya.

Animal and Plant Health Inspection Service (APHIS), 1996. The application of irradiation to phytosanitary problems. Fed. Reg. 16, 24433–24439.

Animal and Plant Health Inspection Service (APHIS), 1998. Use of irradiation as a quarantine treatment for fresh fruits of papaya from Hawaii. Fed. Reg. 63(229) 65645–65649.

Armstrong, J.W., 1994. Heat and cold treatments. In: Paull, R.E., Armstrong, J.W. (Eds.), Insect Pests and Fresh Horticultural Products: Treatments and Responses. CAB International, Wallingford, UK, pp. 103–119.

Burditt, A.K., Hungate, F.P., 1988. Gamma irradiation as a quarantine treatment for cherries infested by western cherry fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 81, 859–862.

Burditt, A.K., Hungate, F.P., 1989. Gamma irradiation as a quarantine treatment for apples infested by codling moth (Lepidoptera: Tortricidae). J. Econ. Entomol. 82, 1386–1390.

Carpenter, A., Potter, M., 1994. Controlled atmospheres. In: Sharp, J.L., Hallman, G.J. (Eds.), Quarantine Treatments for Pests of Food Plants. Westview Press, Boulder, CO, pp. 171–198.

Drake, S.R., Neven, L.G., 1997. Quality response of 'Bing' and 'Rainier' sweet cherries to low dose electron beam irradiation. J. Food Proc. Pres. 21, 345–351.

Drake, S.R., Moffitt, H.R., Eakin, D.E., 1994. Low dose irradiation of 'Rainier' sweet cherries as a quarantine treatment. J. Food Proc. Pres. 18, 473–481.

FAO, 1983. International Plant Quarantine Treatment Manual. FAO Plant Production and Protection Paper 50. Food and Agriculture Organization of the United Nations, Rome, Italy.

Federal Clean Air Act, 1990. Public Law 101-549, enacted November 15, 1990. Washington, DC.

Hallman, G.J., 1994. Controlled atmospheres. In: Paull, R.E., Armstrong, J.W. (Eds.), Insect Pests and Fresh Horticultural Products: Treatments and Responses. CAB International, Wallingford, UK, pp. 121–138.

Hallman, G.J., Armstrong, J.W., 1994. Heated air treatments. In: Sharp, J.L., Hallman, G.J. (Eds.), Quarantine Treatments for Pests of Food Plants. Westview Press, Boulder, CO, pp. 149–163.

Hunter, R.S., Harold, R.W., 1987. The Measurement of Appearance, 2nd edn. Wiley, New York, pp. 1–411.

Mangan, R.L., Shellie, K.C., Ingle, S.J., Firko, M.J., 1998. High temperature forced-air treatments with fixed time and temperature for 'Dancy' tangerines, 'Valencia' oranges, and 'Rio Star' grapefruit. J. Econ. Entomol. 91, 933–939.

Moffitt, H.R., Drake, S.R., Toba, H.H., Hartsell, P.L., 1992. Comparative efficacy of methyl bromide against codling moth (Lepidoptera: Tortricidae) larvae in 'Bing' and 'Rainier' cherries and confirmation of efficacy of a quarantine treatment for 'Rainier' cherries. J. Econ. Entomol. 85, 1855–1858.

Neven, L.G., Mitcham, E.J., 1996. CATTS: Controlled atmosphere temperature treatment system. A novel tool for the development of quarantine treatments. Am. Entomol. 42, 56–59.

SAS Institute, 1985. SAS Users Guide: Statistics. SAS Institute, Cary, NC.

Shellie, K.C., Mangan, R.L., Ingle, S.J., 1997. Tolerance of grapefruit and Mexican fruit fly larvae to heated controlled atmosphere. Postharv. Biol. Technol. 10, 179–186.

Toba, H.H., Burditt, A.K., 1992. Gamma irradiation of codling moth (Lepidoptera: Tortricidae) eggs as a quarantine treatment. J. Econ. Entomol. 85, 464–467.

Toba, H.H., Moffitt, H.R., 1996. Posttreatment development and fertility of nondiapausing codling moth (Lepidoptera: Tortricidae) larvae and their progeny following gamma irradiation. J. Econ. Entomol. 89, 56–62.

Urbain, W.M., 1986. Radiation chemistry of food components and of foods. In: Schweigert, B.S. (Ed.), Food Irradiation. Academic Press, Orlando, FL, pp. 37–82.